APPENDIX A

CAVITATION AT LOCK CULVERT VALVES

A-1. During 1948, a 1:20-scale model of the 11-ft-wide by 12-ft-high valve proposed for the 92-ft lift McNary Lock on the Columbia River between Washington and Oregon was tested in a vacuum tank at the U. S. Army Engineer Waterways Experiment Station.[b] Cavitation induced in the vacuum tank occurred in the cores of large vortexes that were shed randomly from the valve lip. Test results indicated that these large cavities would occur in the prototype unless the invert of the culvert at the valve section was placed at least 163 ft below the upper pool. The prototype was constructed with the invert of the culvert at the filling valves only 112 ft below the upper pool. Six 12-in.-diam air vents, two in the culvert roof and two in the upper portion of each sidewall, were installed immediately downstream of each valve. During initial operation of the lock, the air vents at the filling valves were capped. Pounding noises, resembling thunder or cannon shots, seemed to come from the bulkhead slots on the downstream sides of the filling valves when the valves were partially open. Certainly the collapse of large cavities, such as were indicated by the model, would be expected to result in pounding noises rather than the rattling gravel-type sounds that are heard in cavitating pumps, turbines, etc. With one 12-in.-diam vent open in the roof of the culvert downstream from each filling valve, the pounding noises are eliminated. It is concluded that sufficient air is drawn into this vent to cushion the collapse of the large cavities, eliminate shock pressures, and thus eliminate the pounding noises.

A-2. In the 113-ft lift John Day Lock on the Columbia River between Washington and Oregon, the culvert valves are 12 ft wide by 14 ft high. The culvert roof slopes up at the rate of 1V on l0H, beginning 19 ft from the downstream face of the filling valve recess to a height of 20 ft. This, together with the depth at which the culvert is placed, results in positive pressure on the roof of the culvert throughout the filling cycle. Although vents are installed downstream from the valve, they do not draw air during a normal 4-min valve time filling operation; however, severe pounding noises emit from the culvert.

A-3. In order to develop a method for improved operation of John Day Lock and to obtain data for design of future locks, cavitation tests were conducted at Holt, John Day, and Millers Ferry Locks.

A-4. General dimensions and elevations for the three locks at which tests were made are listed below:

Table A-1

Item	Holt	John Day	Millers Ferry
Location	Warrior River, Alabama	Columbia River, Washington-Oregon	Alabama River, Alabama
Chamber dimensions, ft	110 x 670	86 x 685.4	84 x 655
Type of filling system	Interlaced lateral	Split lateral	Bottom Longitudinal
Normal upper pool el	186.5	268	80
Min lower pool el	122.9	155	32
Max lift, ft	63.6	113	48
Size of reverse tainter valves, ft (width x height)	12.5 x 12.5	12 x 14	10 x 10
Culvert roof at filling valves, el	115	128	26
Size of culverts downstream from filling valves, ft (width x height)	12.5 x 15.5†	12 x 20††	10 x 10

† The culvert roof slopes up at the rate of 1V on 8H beginning at the downstream face of valve recess.
†† The culvert roof slopes up at the rate of 1V on 10H beginning 19 ft from the downstream face of the valve recess.

A-5. During normal operation at Holt and Millers Ferry Locks, the filling valves are opened in 4 and 2 min, respectively; and a controlled amount of air is admitted to the system through vents downstream from the filling valves. Performance of the filling system at each of these locks is very satisfactory. At John Day Lock, the valves are opened in about 15 min, as pounding noises occur when the valves are opened at a faster rate.

A-6. Cavitation observations were made at all three locks with the air vents at the filling valves sealed; thus, no air was admitted to the culvert system during filling operations. Prior to starting each test, the filling valves were held at a small opening until the lock chamber water surface was raised to a predetermined level; the valves were closed and the system was allowed to stabilize. A normal filling operation then was performed. This procedure was repeated with various initial water-surface elevations in the lock chamber.

A-7. In the valve wells at Holt and Millers Ferry Locks, measurements were made of sound levels and recordings were made of sounds. Also, total valve time, constancy of valve movement, and initial water-surface elevations in the upper pool and lock chamber were noted. Formal reports were not prepared on these observations. At John Day Lock, 13 simultaneous measurements were made and recorded, both on magnetic tape and a light-beam oscillograph. Data taken included: valve position, lock water-surface elevation, pressures in the culvert at six points, sound at top of valve well, and air flow in vents. Results of these tests are described in reference c in paragraph 1-3.

A-8. Two phases of the test results are of primary interest in this manual. First, pressure measurements in the culverts at John Day Lock were made to determine the magnitude of pressures concurrent with the loud booms. It was found that the booms were accompanied by rapid pressure fluctuations from one atmosphere negative to about 100 psi positive. While these pressure conditions were most severe a short distance downstream from the filling valve, they carried throughout the system and were reduced only about 50% in the culvert immediately upstream from the emptying valve. Certainly, pressure conditions such as these cannot be tolerated for extended periods of operation without expectancy of a structural failure somewhere in the system. In a special test, bulkheads in the slot upstream from an emptying valve were unseated by the negative phase of the pressure surge. Thus, in a lock where cavitation might occur at the filling valves, a culvert should never be used for filling when the emptying valve for that culvert is bulkheaded off for maintenance or repairs. The second item of primary interest is the determination of conditions for incipient cavitation at each of the projects.

A-9. Data from the two tests that bracketed incipient cavitation at each project are tabulated below:

Table A-2

Item	Project					
	Holt		John Day		Millers Ferry	
	Test 2	Test 6	Test 2A	Test 3B	Test 5	Test 6
Initial Conditions (Observed)						
Upper pool el	186.3	186.3	262.3	262.8	80.3	80.3
Lock water surface el	144.0	140.5	180.0	169.5	46.0	45.0
Lift, ft	42.3	45.8	82.3	93.3	34.3	35.3
Culvert roof at valve, el	115	115	128	128	26	26
Submergence culvert roof at valve., ft	29	25.5	52	41.5	20	19
Valve Time, min (Observed)	3	3	4	4	2	2
Conditions at K , min (Computed)						
Valve open, %	61.5	61.5	57.1	57.1	59.5	59.5
P	15.9	10.1	24.3	7.1	13.2	11.7
V	62.0	64.8	85.6	91.7	53.8	54.7
K (see para 2-2b)	0.819	0.661	0.504	0.307	1.029	0.964
Comments	Quiet	One distinct boom	Quiet	Several loud booms	Quiet	Coughing noises

A-10. Cavitation at Holt and John Day Locks was indicated by very similar pounding noises that resembled thunder or cannon shots. When test conditions were such that cavitation was incipient, the booms occurred only when the valve was near 60% open. As conditions for cavitation were made more severe, booms were observed progressively at valve positions both less and more than 60% open; but there was no noticeable change in the intensity of the sound of the booms. At Millers Ferry Lock, cavitation was indicated only by coughing noises; and observers questioned whether these noises were accompanied by serious pressure fluctuations. With the level rather than the upsloping roof of the culvert downstream from the Millers Ferry valve, the pressure rise in the culvert certainly is more gradual than at Holt and John Day Locks. Also, during the tests, the most severe conditions for cavitation which were allowable (lift 42.5 ft with lower pool 11.5 ft above roof of culverts at filling valves) resulted in velocities less than those at which cavitation was observed at the other locks. Thus, it is probable that the collapse of the cavities was not sudden enough to produce loud sharp booms. However, at higher velocities loud sharp booms were produced in the McNary conduit which also has a level roof.

A-11. Engineers of the Mobile District have concluded that optimum operating conditions result with 6-in. orifice plates at Holt and 3-in. orifice plates at Millers Ferry in the two 12-in.-diam vents at each filling valve. It has been recommended that the valves at John Day Lock be opened to a 30% opening as rapidly as is feasible, maintained at this opening for 5 min, and then opened as rapidly as feasible to the fully open position. This requires a total time for opening the valves of about 6-3/4 min. During the tests it was verified that the above procedure eliminates the loud noises attributed to cavitation and results in a filling time of about 13 min rather than 16 min when the valves are opened at a constant speed in 15 min.